Productivity of the bottomland hardwood forest at the Olentangy River Wetland Research Park before restoration

Matthew W. Cochran and Virginie Bouchard

School of Natural Resources, The Ohio State University

Introduction

Bottomland hardwood forests are located along riparian strips between rivers and upland systems (Odum, 1981). Humans have negatively impacted bottomlands by logging, clearing and draining them for agriculture and development. Along rivers that are channelized and diked, bottomlands do not have a regular flooding regime (Friedman et al., 1996; Friedman et al., 1998) and many major ecological functions are altered, including a reduction in productivity and integrity (Odum, 1978). According to the subsidy-stress concept, flooding can both enhance and stress a riparian ecosystem, depending on frequency, timing and intensity (Odum, 1978; Odum et al., 1979). Flooding of bottomlands affects soil chemistry by producing anaerobic conditions, importing and removing organic matter, and replenishing mineral nutrients (Odum, 1978; Odum et al., 1979; Vannote et al., 1980). Stress of the ecosystem occurs when flooding persists for long periods of time and/or includes very deep water (Green, 1947; Broadfoot, 1967, 1973; Broadfoot and Williston, 1973; Odum, 1978; Odum et al., 1979).

Bottomland hardwood forests are considered one of the most productive wetland ecosystems because of the constant source of water and nutrients (Odum, 1978). Aboveground net primary production (ANPP) is one way of measuring bottomland integrity. In this study, ANPP is defined as the combination of wood and leaf litter production and expressed in g m^{-2} yr^{-1}. A bottomland hardwood forest produces from 300 to more than 2000 g m^{-2} yr^{-1} where an upland forest produces an average of 1000 g m^{-2} yr^{-1} (Conner, 1994; Megonigal et al., 1997). The goal of this research was to quantify the ANPP of the bottomland hardwood forest located at the Olentangy River Wetland Research Park, in respect with flooding frequency. This site presents an interesting experimental setting to test the stress-subsidy concept in northern regions: some areas of the forest are isolated from the river with a dike while other areas are flooded more frequently.

Methods

Site Location

The site is located at the Olentangy River Wetlands Research Park (ORWRP) in Franklin County. The 5.2 ha bottomland hardwood forest varies from 25 to 90 m wide and is approximately 730 m long. This site has a dike at the north end, approximately 3 m tall and 250 m long, which diverts the river away from the bottomland forest. The northern end floods from the Olentangy River only during exceptional floods (Acton et al., 1998) but does flood from rising groundwater when the river stage is high. The southern end floods more frequently than the northern end from a rise in river level (Acton et al., 1998). Plots 1, 2 and 3 at the ORW are considered “diked plots” while 4, 5, 6, 7 and 8 are “non-diked plots”. Box elder (*Acer negundo* L.), eastern cottonwood (*Populus deltoides* Bart. ex Marsh) and eastern sycamore (*Platanus occidentalis* L.) dominate the site.

Transects were established at all three sites along an elevation gradient, perpendicular to the river. Study plots were established along each transect and were 20 m wide by 25 m in length (e.g., 500 m^2). Hydrology information was collected from a United States Geological Survey (USGS) Station (#03226800) along the Olentangy River in Worthington, Ohio. Each site was visited during various flooding events in 2000 to determine at what flow rate each plot started to flood. From this information, historical flow records were used to determine the minimum number of days that each plot started to flood.

Within each plot, every tree with a diameter at breast height (dbh) (1.3 m) greater than 5 cm was identified to species using field guides (Petrides, 1988; Little, 1998). The diameter was measured for all trees in order to calculate the basal area of the plot. Five canopy trees (i.e., dbh greater than 25 cm and taller than 10 m) occurring inside each study plot were cored to estimate woody production. A modified version of the point-quarter method (Curtis and Cottam, 1962) was used to determine which trees were selected for coring. The heights of the cored trees were measured using a clinometer.

Leaf Litter

Leaf litter traps were placed randomly inside each study plot and were secured to the ground with stakes to assure no losses from flooding. Five litter traps were placed in each plot for a total of 40 at the ORW. Leaf litter was collected once a week during autumn months when trees lose most of their leaves (Newbould, 1967). Leaf litter was collected June 15 to Dec. 30 1998 (Bouchard and Mitsch, 1999: 198 days), Oct. 4, 1999 to Jan. 5, 2000 (this study: 94 days), and Sept. 5 to Dec. 5, 2000 (this study: 92 days). The leaf litter was collected every 14 days, sorted into leaves, fruits and twigs, dried at 105ºC, and weighed to the nearest 0.1 g.

Tree Cores

All trees were cored with a 5.15 mm inside diameter increment borer at breast height (1.3 m). Each tree had two cores taken at 90° angles and averaged together to account for variation in tree growth. Tree cores were collected, prepared and measured according to Phipps (1985). Each core penetrated the tree to a depth of 15 cm to capture at least the last twenty years of growth. The cores were temporarily stored in paper straw until air dry, and then permanently glued onto grooved wooden holders. The cores were prepared for ring analysis by sanding with a series of sandpaper (80, 120, 220, 400, 600 grit) then polished with lamb's wool. The growth rings were examined for general growth patterns, then each ring was measured to 0.01 mm using a mechanical stage and dissecting microscope with crosshairs. This analysis occurred at the Tree Ring Analysis Lab in Wooster, Ohio.

Estimation of Ecosystem Production (ANPP)

Ecosystem production was calculated following the method of Whittaker and Woodwell (1968). Basal area increase (Ai) ($cm^2\ yr^{-1}$) was calculated using the following equation (Newbould, 1967):

$$A_i = \pi\,[r^2 - (r\text{-}i)^2] \qquad (1)$$

where r = radius of tree at breast height (cm) and i = radial increment per year ($cm\ yr^{-1}$).

The annual wood production per tree (Pi) ($g\ yr^{-1}$) was calculated from the parabolic volume equation (Whittaker and Woodwell, 1968; Phipps 1979):

$$P_i = 0.5\ r\ A_i\ h \qquad (2)$$

where r = wood specific gravity ($g\ cm^{-3}$) and h = tree height (m). Wood specific gravity values were obtained from the U.S. Forest Products Laboratory (1974).

The plot wood production (Pw) ($g\ m^{-2}\ yr^{-1}$) was calculated following Whittaker and Woodwell (1968) using the following equation:

$$Pw = \hat{A}[P_i]*BA/Bc \qquad (3)$$

where BA = basal area of entire plot, m^2(wood) m^{-2} (site) and Bc = basal area of cored trees in plot, m^2 (wood).

ANPP for each plot was estimated by summing the average plot leaf litter production ($g\ m^{-2}\ yr^{-1}$) and average plot wood production ($g\ m^{-2}\ yr^{-1}$). ANPP for each site was estimated by averaging all the plot estimates of ANPP.

Results

Bankfull Discharge

Based on elevation, the northern end of the ORW site (plots 1, 2 and 3) starts to receive floodwater over the dike when the river flow equals 12 $m^3\ sec^{-1}$ (4400 $ft^3\ sec^{-1}$). From groundwater well data, plot 1 starts to flood from groundwater when the river reaches 4 $m^3\ sec^{-1}$ (1500 $ft^3\ sec^{-1}$). Although not considered diked, plot 4 also starts to receive floodwater when the river flow equals 12 $m^3\ sec^{-1}$ (4400 $ft^3\ sec^{-1}$). Plots 6, 7 and 8 start to receive floodwater when the river flow equals 9 $m^3\ sec^{-1}$ (3200 $ft^3\ sec^{-1}$). Plot 5 starts to receive floodwater at a slightly higher flow rate than plots 6, 7 and 8 because of the rolling topography. Because the dike doesn't influence the southern end, groundwater is not trapped; instead only river water floods this part of the site.

The northern part of the ORW ranges in the minimum number of flood days during the growing season from 0 days in 1992 and 1996-2000 to 4 days in 1995 (Table 1). The southern end ranges from 0 days in 1991 to 6 days in 1995 and 1998 during the growing season (Table 1). Also, plot 1 floods from ground water during the growing season a minimum of 2 days in 1991 to 26 days in 1992 (Table 1).

Table 1. Average minimum number of days that each site was presumably flooded during the growing season. () indicates total minimum number of days flooded during the entire year.

North end		South end	
	River	Groundwater	River
1990	1 (3)	23 (55)	3 (10)
1991	0 (6)	2 (18)	0 (7)
1992	0 (0)	26 (33)	5 (9)
1993	0 (1)	9 (39)	0 (8)
1994	0 (5)	19 (33)	2 (7)
1995	4 (4)	23 (36)	6 (6)
1996	0 (0)	22 (55)	3 (19)
1997	0 (0)	10 (24)	5 (9)
1998	0 (0)	18 (32)	6 (6)
1999	0 (0)	9 (29)	1 (5)
2000	0 (0)	17 (37)	5 (8)

Leaf Litter Production

The ORW site showed no significant difference when comparing leaf litter production between the plots.

Wood Production

A significant difference was found in the average wood production at ORW between the diked plots and the non-diked plots for every year except 1997 ($p < 0.05$) (Figure 1). Over the ten-year period, the diked plots at ORW averaged 158 ± 32 $g\ m^{-2}\ yr^{-1}$, while the non-diked plots averaged 521 ± 58 $g\ m^{-2}\ yr^{-1}$.

Estimation of ANPP

The ORW as a site had an average ANPP value of 805 ± 299 $g\ m^{-2}\ yr^{-1}$. There was a significant difference between the average ANPP of diked plots and non-diked plots (p-value = 0.027) at ORW for the year 2000 (Figure 2). The diked plots averaged 530 ± 92 $g\ m^{-2}\ yr^{-1}$ while the non-diked plots averaged 971 ± 247 $g\ m^{-2}\ yr^{-1}$.

Discussion

A number of studies have demonstrated that bottomland hardwood forests that are connected to an adjacent body of running water and temporally flooded during periods of high water are generally more productive than bottomlands disconnected from the river or flooded during long periods of time (Green, 1947; Broadfoot, 1967, 1973; Broadfoot and Williston, 1973; Johnson and Bell, 1976a, 1976b; Mitsch, 1979; Mitsch and Ewel, 1979; Brown and Peterson, 1983; Taylor et al., 1990; Mitsch et al., 1991; Megonigal et al., 1997; Dudek et al., 1998; Burke et al., 1999; Robertson et al., 2001). These results generally support the subsidy-stress concept (Odum, 1978; Odum et al., 1979) that has been applied for a number of "coupled systems" (i.e., salt marshes and tidal events, freshwater coastal marshes and seiche events, riparian systems and floods).

The existence of a hydrological interdependence between aquatic systems and their adjacent terrestrial ecosystems is known to be one of the most important forcing functions that

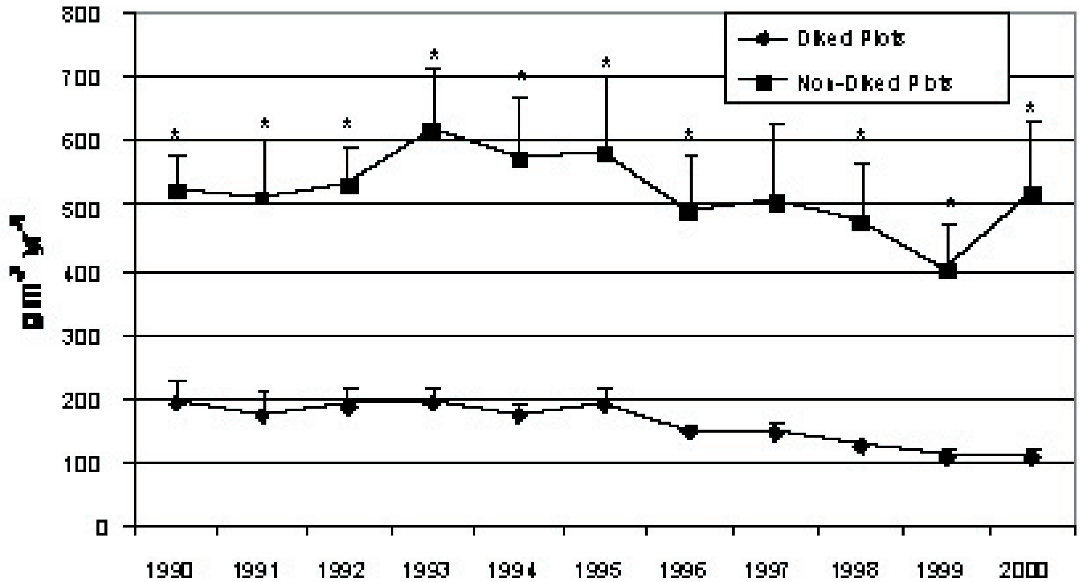

Figure 1. Average wood production (± 1 SE) at the diked (n = 15) and non-diked (n = 25) plots within the ORW site. (*) denotes a significant difference between the diked and non-diked plots at the 95% level.

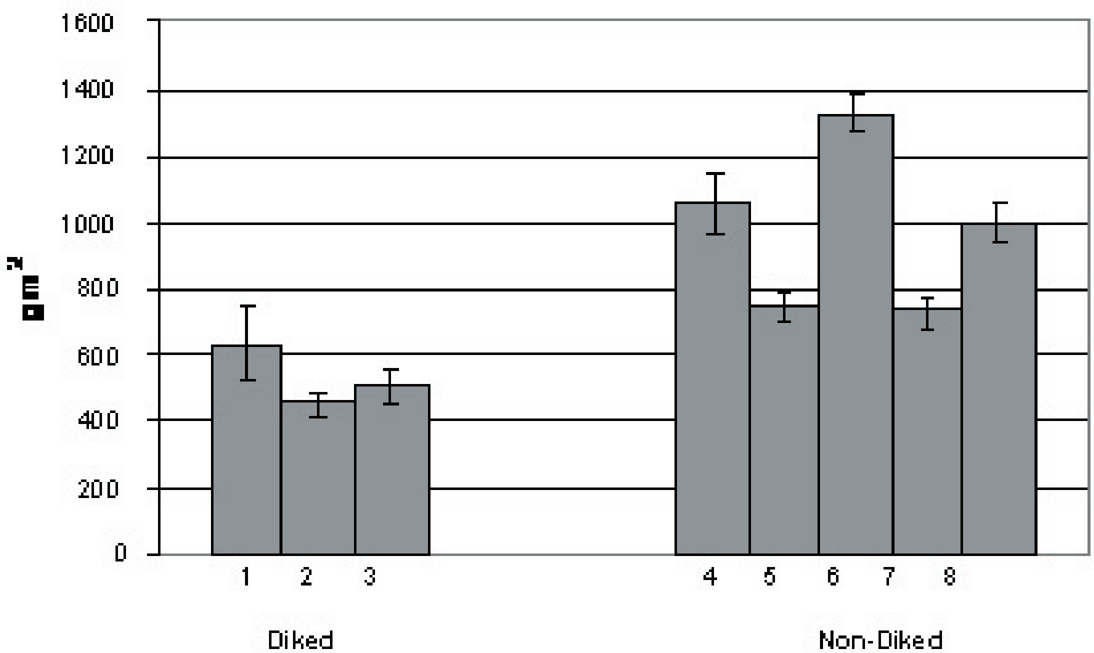

Figure 2. Average ANPP (± 1 SE) of diked and non-diked plots at ORW.

drives the ecological integrity of both systems. Ecotones influenced by a regular pulsing hydroperiod are more productive than systems that don't receive floodwaters on a regular basis (Mitsch, 1979; Odum et al., 1979). However, the subsidy to the productivity of bottomland ecosystems by floods has been primarily quantified in the southern United States where bottomlands are often referred to as "swamps" and dominated by bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*) and Atlantic white cedar (*Chamaecyparis thyoides* (L.) B.S.P.).

The lower production at plots 1, 2, and 3 is attributed to the presence of a dike that was built in the late 1930s to protect agricultural fields from flooding. The dike acted as a barrier that excluded the subsidy of the access water, nutrients and sediments that are typical of a flood event (Odum, 1978; Odum et al., 1979). Also, the stress to flood-intolerant species associated with complete inundation was missing (Odum, 1978; Odum et al., 1979), as well as the importing and exporting of organic matter and mineral nutrients back into the river (Vannote et al., 1980). The elimination of flooding stress resulted in the colonization of flood-intolerant species that are associated with lower production when found in bottomlands (Johnson and Bell 1976a, 1976b; Brown and Peterson, 1983; Megonigal et al., 1997).

References

Acton, W.T., W.J. Mitsch, N. Wang and V. Bouchard, (1998). Flooding frequency and groundwater gradient of a riparian hardwood forest. In: W.J. Mitsch and V. Bouchard (eds.), Olentangy River Wetland Research Park at the Ohio State University, Annual Report 1997. School of Natural Resources, The Ohio State University, Columbus, OH. pp. 175-182.

Bouchard, V. and W.J. Mitsch, (1999). Pre-restoration study of the bottomland forest at the Olentangy River Wetland Research Park. In: W.J. Mitsch and V. Bouchard (eds.), Olentangy River Wetland Research Park at the Ohio State University, Annual Report 1998. School of Natural Resources, The Ohio State University, Columbus, OH. pp. 175-182.

Broadfoot, W.M., (1967). Shallow water impoundment increases soil moisture and growth of hardwoods. Soil Science Society of America Proceeding 31: 562-564.

Broadfoot, W.M., (1973). Raised water tables affect southern hardwood growth. U.S. Forest Service Research Note SO-168.

Broadfoot, W.M. and H.L. Williston, (1973). Flooding effects on southern forests. Journal of Forestry 71: 584-587.

Brown, S. and D. L. Peterson, (1983). Structural characteristics and biomass production of two Illinois bottomland forests. American Midland Naturalist 110: 107-117.

Burke, M.K., B.G. Lockaby and W.H. Conner, (1999). Aboveground production and nutrient circulation along a flooding gradient in a South Carolina Coastal Plain forest. Canadian Journal of Forestry Research 29: 1402-1418.

Conner, W.H., (1994). Effects of forest management practices on southern forested wetland productivity. Wetlands 14: 27-40.

Curtis, J.T. and G. Cottam, (1962). Plant ecology workbook: laboratory field and reference manual. Burgess Publishing Company, Minneapolis, 161 p.

Dudek, D.M., J.R. McClenahen and W.J. Mitsch, (1998). Tree growth responses of Populus deltoides and Juglans nigra to streamflow and climate in a bottomland hardwood forest in central Ohio. American Midland Naturalist 140: 233-244.

Friedman, J.M., W.R. Osterkamp and W.M. Lewis, Jr., 1996). Channel narrowing and vegetation development following a Great Plains flood. Ecology 77: 2167-2181.

Friedman, J.M., W.R. Osterkamp, M.L. Scott and G.T. Auble, (1998). Downstream effects of dams on channel geometry and bottomland vegetation: regional patterns in the Great Plains. Wetlands 18: 619-633.

Green, W.E., (1947). Effect of water impoundment on tree mortality and growth. Journal of Forestry 45: 118-120.

Johnson, F.L. and D.T. Bell, (1976a). Plant biomass and net primary production along a flood-frequency gradient in a streamside forest. Castanea 41: 156-165.

Johnson, F.L. and D.T. Bell, (1976b). Tree growth and mortality in the streamside forest. Castanea 41: 35-41.

Little, E.L,. (1998). National Audubon Society Field Guide to North American Trees: Eastern Region. Albert A. Knopf, New York, USA.

Megonigal, J.P., W.H. Conner, S. Kroeger and R.R. Sharitz, (1997). Aboveground production in southeastern floodplain forests: a test of the subsidy-stress hypothesis. Ecology 78: 370-384.

Mitsch, W.J., (1979). Interactions between a riparian swamp and a river in southern Illinois. Strategies for Protection and Management of Flood Plain Wetlands and other Riparian Ecosystems. General Technical Report WO-12. Washington, DC, USA, pp. 63-72.

Mitsch, W.J. and K.C. Ewel, (1979). Comparative biomass and growth of cypress in Florida wetlands. American Midland Naturalist 101: 417-426.

Mitsch, W.J., J.R. Taylor and K.B. Benson, (1991). Estimating primary productivity of forested wetland communities in different hydrologic landscapes.

Landscape Ecology 5: 75-92.

Newbould, P.J., (1967). Methods for estimating the Primary Production of Forests. Blackwell, Oxford, England.

Odum, E.P., (1978). Opening address: Ecological importance of the riparian zone. Strategies for Protection and Management of Flood Plain Wetlands and other Riparian Ecosystems. General Technical Report WO-12. Washington, DC, USA.

Odum, E.P., J.T. Finn and E.H. Franz, (1979). Perturbation theory and the subsidy-stress gradient. Bioscience 29: 344-352.

Odum, E.P., (1981). Foreword. In, J.R. Clark and J. Benforado (eds.), Wetlands of Bottomland Hardwood Forests. Elsevier, Amsterdam, The Netherlands. p. xi-xiii.

Petrides, G.A., (1988). Peterson Field Guide: Eastern Trees. Houghton Mifflin Company, New York, USA.

Phipps, R.L., (1979). Simulation of wetlands forest vegetation dynamics. Ecological Modelling 7: 257-288.

Phipps, R.L., (1985). Collecting, Preparing, Crossdating, and Measuring Tree Increment Cores. U.S. Geological Survey Water-Resources Investigations Report 85-4148.

Robertson, A.I., P. Bacon and G. Heagney, (2001). The responses of floodplain primary production to flood frequency and timing. Journal of Applied Ecology 38: 126-136.

Taylor, J.R., M.A. Cardamone and W.J. Mitsch, (1990). Bottomland hardwood forests: Their functions and values. In, J.G. Gosselink, L.C. Lee and T.A. Muir (eds.), Ecological Processes and Cumulative Impacts Illustrated by Bottomland Hardwood Wetland Ecosystems. Lewis, Chelsea, MI, USA. pp. 14-34.

U. S. Forest Products Laboratory, (1974). Wood handbook: wood as an engineering material. USDA Agriculture Handbook No. 72. Washington, DC.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell and C.E. Cushing, (1980). The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Science 37: 130-137.

Whittaker, R.H. and G.M. Woodwell, (1968). Dimension and production relations of trees and shrubs in the Brookhaven Forest, New York. Journal of Ecology 57: 155-174.